Effect of continuous cooking on cooking water properties and pasta quality

Giulia Diamante[a,b,*], **Donatella Peressini**[a], **Michele Simonato**[b], **Monica Anese**[a]

[a]Department of Agricultural, Food, Environmental and Animal Sciences, Via Sondrio 2/A, University of Udine 33100, Italy

[b]The Research Hub by Electrolux Professional, Pordenone 33170, Italy

*Correspondence to: G. Diamante, Department of Agricultural, Food, Environmental and Animal Sciences, Via Sondrio 2/A, University of Udine 33100, Italy. E-mail: diamante.giulia@spes.uniud.it

Abstract

Background: Professional continuous pasta cookers are filled with fresh water. The solids leached from the cooked pasta in cooking water make pasta less firm and stickier while leading to water properties changings and overflow. Water is constantly released and the fresh makeup water has to be reheated. The effect of continuous cooking on cooked pasta quality and water properties was investigated for the first time by simulating professional pasta cooking at laboratory-scale.

Results: Continuous cooking procedure of 12 batches led to a solid content of cooking water of 4% resulting in an increase in shear-thinning behaviour and consistency index. Pasta cooking loss decreased from 5.3 to 3.6% due to the lower water concentration gradient between cooking medium and pasta, and solids acting as physical barrier. This was confirmed by the decrease in swelling index from 2 to 1.6 g water/g dry pasta during the optimal cooking time (13 min 45 s). Surprisingly, continuous cooking made the pasta firmer while stickiness did not significantly differ ($p > 0.05$).

Conclusions: Taking batch number 7 as acceptability threshold, further studies are required to find optimal solution for retaining cooking water properties highly affecting daily cooking procedures in food service kitchens.

Keywords: continuous cooking; spaghetti quality; pasta cooker; cooking water

INTRODUCTION

Pasta is a staple food in much of the world. Versatility, ease of transportation, handling, cooking properties, long shelf life, diversity of form, high digestibility, good nutritional qualities and relatively low cost, make pasta one of the favourite food by consumers.[1–3] Durum wheat (*Triticum turgidum* L. var. *durum*) is the cereal of choice for pasta production because of the peculiar properties of its proteins and gluten, as well as its yellow pigment content.[1] Pasta is traditionally cooked in an excess of fresh water (the recommended pasta/water ratio is 1/10) at boiling temperature.[4] During cooking of pasta, high temperature and high moisture conditions lead to progressive hydration and component solubilisation, resulting in major structural changes, i.e. protein coagulation and starch gelatinization.[5–7] Both structural changes are competitive for water and antagonistic because protein coagulation and interaction, leading to a continuous and strengthened network, are opposed to starch swelling and gelatinization in the network interspaces.[7] Pasta firmness is promoted by protein continuous network entrapping starch particles. On the contrary, pasta tenderness results from a prevalence of starch swelling along with exudate loss, promoting the formation of protein coagulates in discrete masses lacking a continuous network.[8-11] Semolina protein content and gluten strength are important prerequisites for superior pasta cooking quality.[9,12,13] Protein content is classified as low when between 11 and 16%[14,15] while gluten strength is primary a function of the density of reversible disulphide bonds, which are responsible of the desired solid-like behaviour in cooked pasta.[15–17]

Pasta should release minimal material into the cooking water and must be firm and not unduly sticky when cooked for maximum consumer acceptance.[2,18,19] Cooking loss, i.e. leaching of material from the outer layer of pasta in cooking water, is related to the amount of unabsorbed water associated with drained cooked pasta and mainly affects the product stickiness, which is one of the most desired quality parameter. The more leached solid the more stickier the pasta is.[14,20–22] These solids are mainly amylose with a small amylopectin presence only, besides nonstarch polysaccharides and proteins.[23] Pasta stickiness results from substances escaping from the protein network and adhering to the surface of cooked pasta and is related to the proportion of surface material that can be rinsed from the cooked spaghetti following drainage. While semolina characteristics (e.g. protein content and quality, starch damage related to granulation), processing (low and high temperature drying), cooking conditions (e.g. water characteristics, cooking time) and consuming modality (e.g. length of time between draining and testing) are well known factors influencing stickiness, the role of cooking medium has not been fully elucidated yet.[5,13,14,18,21,24] Malcolmson and Matsuo[25] highlighted the importance of cooking medium composition, reporting higher stickiness with harder water.

Similarly, although the mechanism of solid leaching in cooking water during cooking at laboratory-scale has been extensively studied, to the authors' best knowledge, no reports about cooking in pasta cookers are present in the scientific literature.[26] The pasta cooker is filled with fresh water and when the boiling point is reached, pasta automatically enters (industrial continuous pasta cooker) or is manually added (food service pasta cooker) and then removed when it is cooked. The same water batch is used many times (up to 50 and 12 in industry and food service, respectively) to cook pasta. During the continuous cooking process, the solids leached from the cooked pasta might affect cooking water properties and working conditions. Viscosity, colour and flavour of cooking water may change, affecting in turn the final product quality. Also, a foam layer may form upon cooking with consequent overflowing through drain. To reduce solid concentration and address changings, water must be constantly released and replaced by an equal amount of fresh water that has to be heated, with consequent high time and energy consumption and thus operating costs. Therefore, the purpose of this study was to investigate the impact of continuous cooking (in the same cooking water) on the final quality of pasta and the cooking water characteristics. Spaghetti were chosen since they are the most popular pasta form the manufacturers produce today.[20]

MATERIALS AND METHODS

Materials

Durum wheat spaghetti n. 4 (2 mm diameter) were purchased from a specialized supplier to the food service sector (Marr, Italy). The composition of the pasta as supplied by the manufacturer (Rummo, Benevento, Italy) was: protein 12.5 g/ 100 g, carbohydrate 71.5 g/ 100 g, fiber 2.8 g/ 100 g, and fat 1.6 g/ 100 g.

Cooking procedure

Professional cooking procedure was performed in a pasta cooker (Electric Pasta Cooker, 1 Well 40 Litres, Electrolux Professional S.p.A., Pordenone, Italy) based on standard use: spaghetti strands (3 kg) were placed in steel vessel and cooked for 11 min in 36 L of tap boiling water with no salt added. Pasta was strained above the tank and fresh water was added for making up the initial volume. Up to 7 batches were cooked.

The laboratory-scale cooking procedure was set up to emulate continuous cooking procedure used by food service operators. The flow chart of a single cooking cycle is shown in Fig. 1. To perform continuous cooking a colander fitting in a 500-mL beaker was used. Spaghetti strands (25 g) were cut into equal lengths of 5.0 mm and placed in the colander (Fig. 1a). Pasta was cooked in 300 mL of tap boiling water with no salt added (Fig. 1b). Stirring was frequently performed, especially in the first cooking minutes, with a smooth plastic stick. Pasta was then strained and rinsed with tap boiling water above the beaker (Fig. 1c) to reach 300 mL of volume for the next batch and retain solids in the cooking water. Up to 12 batches were cooked in the same colander with the same procedure as previous.

Cooked pasta from each batch was analyzed for cooking loss, swelling index, and textural characteristics. Cooking water from each batch was analyzed for solid content and rheological properties.

Determinations

Optimal cooking time

During cooking, the optimal cooking time (OCT) was evaluated by taking a sample strand of pasta every 30 s and observing the time of disappearance of the core of spaghetti, by squeezing it between two Plexiglas® plates, according to the AACC Approved Method 66-50.[27] The time at which the core completely disappeared was taken as the OCT.

Cooking loss and water solid content

According to the Approved Method 66-50,[27] slightly modified, pasta was poured into a Bückner funnel above an aluminum vessel while collecting cooking water and rinsed with 100 mL of cold distilled water. Rinsing and cooking waters were combined and hereafter named as cooking water for simplicity. Only for pasta cooker, 300 mL of cooking water from tank was collected for analysis. Cooking water was weighted, placed in an air oven at 105 °C and evaporated until constant weight was reached. Cooking loss of pasta was expressed as the percentage of the total dry pasta cooked at each cooking batch and solid content of cooking water as percentage of the cooking water before drying.

Overflow and wastewater volume in pasta cooker

The overflow was measured as the number of times in which cooking water flew through overflow per cooking batch and the wastewater volume as the volume (L) of water measured by weighing discharged water from drainage pipe.

Swelling index

The swelling index of cooked pasta (g water/g dry pasta) was determined according to the procedure described by Foschia *et al*.[28] Pasta was weighed after cooking and dried in an air oven at 105 °C to a constant weight. The swelling index was expressed as Eq. 1:

$$Swelling\ index\ = \frac{W_c - W_d}{W_d} \quad (1)$$

where W_c is weight of cooked pasta (g) and W_d is weight of pasta after drying (g).

Textural characteristics

Textural properties of cooked pasta samples were evaluated using a Texture Analyser (TA.XT plus, Stable Micro Systems Ltd., Godalming, UK) equipped with a 5 kg load cell. Before being tested, pasta samples were allowed to rest at 25 °C for 10 min in a covered container.[21] Only for firmness, cooked pasta was rinsed with 100 mL of cold distilled water.

Pasta firmness was determined according to the Approved Method 66-50[27] using a light knife blade (A/LKB) (speed 0.17 mm s^{-1}) and was expressed as the maximum cutting force (N) required to cut five pasta strands. Pasta stickiness was evaluated using a pasta stickiness rig (HDP/PFS) at a compression speed of 0.5 mm s^{-1} and compression force of 1 kg for 2 s. It was defined as the maximum peak force (N) to separate the probe from five pasta strands surface upon probe retraction.

Rheological properties

The rheological measurements were carried out using a RS6000 Rheometer (Thermo Scientific RheoStress, Haake, Germany), equipped with a coaxial cylinder geometry (CCB25 Din) and Peltier system for temperature control. Cooking water was allowed to cool down in a water bath (15 ± 5 °C) for 30 min under gentle magnetic stirring. Measurement were conducted at 25 and 80 ± 0.01 °C. Before any measurements were taken, samples rested for 5 min at the selected temperature after loading. Steady shear measurements (flow curves) were performed over a shear rate range from 3 to 100 s^{-1}. The power law model was used to fit the flow data (Eq. 2):

$$\sigma = K\dot{\gamma}^{n} \qquad (2)$$

where σ (Pa) is the shear stress, $\dot{\gamma}$ (s^{-1}) is the shear rate, K (Pa s^n) and n (dimensionless) are the consistency and flow coefficients, respectively.

The consistency coefficient (K) was used to determine the viscosity-concentration relationship. The concentration dependence of the consistency coefficient at the two temperatures was examined using an exponential (Eq. 3) and a power law model (Eq. 4)[29]:

$$K = ae^{(bC)} \qquad (3)$$

$$K = aC^{b} \qquad (4)$$

where K (Pa s^n) is the consistency coefficient and C (%) is the solid concentration of cooking water. Parameters *a* and *b* were calculated for each model.

Statistical analysis

All experiments were performed in triplicate unless otherwise mentioned. Textural data for firmness and stickiness are mean of thirty and fifteen measurements (from three different cooking replications), respectively. Statistical differences in pasta and solid content in cooking water were determined by one-way analysis of variance (ANOVA) and Tukey's comparison test ($p < 0.05$). The goodness-of-fit was evaluated based on statistical parameters of fitting (coefficient of determination, R^2 and standard error). The statistical software, R (The R foundation for statistics, v. 3.0.3), was used for the analysis.

RESULTS AND DISCUSSION

Continuous cooking procedure was preliminary investigated in a professional pasta cooker for up to 7 batches. Preliminary experiments showed that above this batch threshold pasta was perceived as sticky and cooking water colour turned into dark yellow with off-flavour. Moreover, excessive formation of foam and waste of water were observed. Solid content in the collected cooking water progressively increased approaching a saturation point (Fig. 2). The overflow occurred approximately 6 times per cooking batch with a wastewater volume of 21 L, counting 58.3% of the initial tank volume. Water consumption during cooking is due to evaporation, water absorption by product and water lost through overflow that occurs as a consequence of foam formation due to leached components from pasta.[30,31] While evaporation and water absorption cannot reasonably be managed to reduce wastewater and address product/water changings, wastewater though overflow might be faced by managing cooking water properties and cooking procedure.

To this purpose, industrial pasta cooking procedure was simulated at laboratory-scale (Fig. 1) to investigate the effect of continuous cooking on pasta quality and cooking water properties under controlled conditions.

The OCT , i.e. time when the starch central core has disappeared and the starch can be considered to be fully gelatinized,[32] was 13 min 45 s.

Table 1 shows the solid content of cooking water, as well as pasta cooking loss and swelling index after one by one continuous cooking of up to 12 pasta batches, corresponding to 3 hours of continuous cooking. As expected, the solid content progressively increased, similar to solid content of cooking water in pasta cooker (Fig. 2). This solid concentration slowly approached the saturation point, which was not achieved within batch range of the experimental work.

Increasing the batch number, cooking loss and swelling index of spaghetti progressively decreased from 5.3 to 3.6% and from 2.0 to 1.6 g water/g dry pasta, respectively (Table

1). Cooking loss is commonly used as a predictor of overall cooking performance by both consumers and industries and it is generally accompanied by a mass transfer of water from cooking medium into the pasta, quantified by the swelling index.[2,3,33] Pasta that features up to 6, 8 and 10% solid loss is considered quite good, regular and poor, respectively.[34] Consequently**,** pasta under our investigation can be considered good, which was confirmed by swelling index values in agreement with the literature.[2,35] During continuous cooking, the solid content increase in cooking water would limit an efficient heat and mass transfer through the strand (reduced concentration gradient) leading to lower hydration and partly swelling of starch granules at OCT. The lack of the arrangement of starch polymers inside the granule would result in lower solid leaching from pasta matrix during cooking.[36] This finding supports the hypothesis of Sissons and Batey[37] that lower swelling is related to a reduced tendency for the granules to leach their contents into the surrounding liquid. Moreover, solids in cooking water might act as a physical barrier on product surface hindering particles from leaching, which probably fill small pores in the gluten network. Furthermore, part of the leached solids out of the granule may be aggregated in the protein network partly restricting further granule swelling. Amylose is believed to act as a restraint on swelling and starch granules do not show complete swelling until amylose has been leached out of the granules.[38] These results can hardly be compared with data of the literature since the role of cooking water on cooking loss and swelling index has been investigated in terms of cooking water composition instead of leached solid concentration, as in the present investigation. Specifically, Malcolmson and Matsuo[25] reported higher cooking loss with increased water hardness and when pH was raised over 8; same was concluded when pasta was cooked in water with salt.[39]

Fig. 3 shows textural values of spaghetti cooked under continuous cooking. Firmness value of first batch (i.e. pasta cooked in fresh water) can be ascribed to the low protein content, indicated in the label by the manufacturer. Increasing cooking batch would make the pasta significantly firmer ($p < 0.05$). This can be due to the solid retention inside the starch–protein structure and the partial swelling of starch granules, also reflected in the decrease in cooking loss. This further supports our hypothesis that soluble material was entrapped and did not diffuse in cooking water. Upon cooling, aggregated amylose outside the granules retrograded stabilizing the gluten network and adding firmness to the pasta.[38] Also other starch modifications (e.g. amylopectin melting) may supersede amylose content in imparting firmness.[4]

Stickiness did not differ significantly ($p > 0.05$) remaining surprisingly unaffected within the range of batch number tested (Fig. 3). This can be explained by both mass and composition factors thus referring to surface material quantity and quality, respectively. Surface material quantity might change because of surface material leaching kinetic. Constant stickiness values with the higher batch number indicated constant material amount stuck to the surface. This result disproved the hypothesis that lower cooking loss (Table 1) is attributed to lower stickiness,[15,39] while bearing out that total solids lost to cooking water might not necessarily be related to stickiness, as indicated by Dexter *et al.*[21] Surface material quality might change because of the extent of starch gelatinization[40] and the amount of soluble carbohydrate, amylose and amylopectin fragments, exuding from the starch granules during cooking.[8,18] Since instrumental stickiness did not change during continuous cooking, the mouthfeel stickiness might be related to flow properties of cooking water.[31]

In light of the pasta quality values observed, the main issue of continuous cooking procedure may be related to cooking water properties, which is indeed indicated by food service operators. Flow properties were investigated at room temperature (25 °C) and at the closest temperature to boiling point (80 °C), simulating condition of use. Fig. 4 shows the flow curves at 25 °C of cooking water at different batches. In accordance with Che *et* *al.*[41] for starch solutions, flow curves of the dispersions showed shear thinning behaviour under steady shear flow and the same trend was observed for flow curves at 80 °C (data not shown). The decrease in viscosity with the increase in shear rate can be attributed to the disentanglement of polymer chains under shear flow and breaking of possible structure in solution. This flow behaviour was described by a power law model (Eq. 2) and the corresponding parameters are summarized in Table 2. Flow index (n) is dimensionless and reflects the closeness to Newtonian flow (n=1), while consistency coefficient (K) indicates viscosity at a shear rate of 1.0 s^{-1}.[42] The coefficients of determination (R^2) were very close to 1, indicating that the selected model was adequately suitable for describing the flow behaviour of samples.[43] n values of 0.83-0.98 at 25 °C are consistent with a shear thinning behaviour while at low batch number and 80 °C Newtonian behaviour was observed.[29] These results may be attributable to the relatively low concentration of solids. At 25 and 80 °C, n decreased with batch number due to more entanglements that break upon flow. Increasing temperature from 25 to 80 °C led to higher flow index, which indicates that cooking water tends to be more shear thinning at lower temperatures. K values increased from 1.4 to 31 $mPa \cdot s^n$ at 25 °C and from 0.5 to 21 $mPa \cdot s^n$ at 80 °C increasing batch number. The viscosity increase due to a higher solid content may result from increased restriction of molecular motion due to entanglements between polymer chains.[44,45]As expected, K decreased with the increase in temperature, indicating a lower apparent viscosity at higher temperatures.[43,46]

The effect of solid concentration on flow behaviour of cooking water can be obtained from parameters of rheological models, which are generally power or exponential relationships using apparent viscosity values at 50 s^{-1}, which corresponds to effective oral shear rate.[44,47] Consistency coefficient (K) instead of apparent viscosity at 50 s^{-1} was used since pasta cooking water was not intended for consumption. The coefficients of determination (R^2) were higher for exponential (Eq. 3) than power law (Eq. 4) model.

Therefore, the former was selected being more suitable in describing the solid concentration effect[48] and the regression model parameters "*a*" and "*b*" are summarized in Table 3. At 80 °C and thus close to the temperature of use in pasta cooker, parameter "*a*" was lower while parameter "*b*" was higher, indicating a stronger dependency of consistency coefficient on concentration. These results are in line with those reported by Marcotte *et al.*,[29] who investigated exponential models for food hydrocolloids such as carrageenan, pectin, gelatine, starch, and xanthan.

Taking into consideration the indication provided by food service staff, batch number 7 is the acceptability threshold for working conditions and thus corresponding n and K values should be the reference for future works with the aim of improving kitchen working conditions, limiting overflow while retaining high product quality throughout the service.

CONCLUSIONS

The effect of professional continuous cooking on cooked pasta quality and water properties was investigated for the first time by simulating professional pasta cooking at laboratory-scale. Up to 3 hours of continuous cooking (i.e. 12 cooking batches) resulted in decreasing cooking loss and lower swelling index of spaghetti. Solid content in cooking water progressively increased leading to a shear thinning behaviour of cooking water, which exhibited Newtonian behaviour at low solid content but high temperature. Increasing cooking batch during continuous cooking made the pasta firmer, due to the solid retention inside the starch-protein network and the only partial swelling of starch granules. Surprisingly, stickiness remained unaffected during continuous cooking. In light of these results, food service staff might be reassured about pasta stickiness while further research is needed to find feasible solutions for retaining cooking water properties that highly affect daily cooking procedures in food service kitchens.

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All authors conceived the study. GD carried out the experiments in conjunction with DP. All authors participated in manuscript revisions and discussion, coordinated and critiqued by MA.

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FIGURE LEGENDS

Figure 1. Flow chart of cooking cycle: **a)** Pasta loading, **b)** Cooking batch, **c)** Rinsing, straining, unloading

Figure 2. Solid content of cooking water in pasta cooker as a function of pasta batch number

Figure 3. Firmness and stickiness values (N) of cooked pasta as a function of batch number; means ± standard deviations with the same letter are not significantly different ($p > 0.05$)

Figure 4. Apparent viscosity as a function of shear rate for different batch numbers of cooking water at 25 °C

Table 1. Effect of batch number on technological properties of cooking water and pasta samples

Batch number	Solid content (%)	Cooking loss (%)	Swelling index (g water/g dry pasta)
1	0.53^{e}	5.27^{a}	1.95^{a}
2	0.77^{e}	5.03^{ab}	1.92^{a}
3	1.37^{d}	5.02^{bc}	1.90^{a}
4	1.62^{d}	4.82^{bc}	1.87^{ab}
5	2.12^{c}	4.54^{bcd}	1.88^{a}
6	2.41^{bc}	4.33^{cd}	1.84^{ab}
7	2.65^{b}	4.11^{de}	1.86^{ab}
9	3.28^{a}	4.10^{de}	1.75^{b}
12	3.66^{a}	3.57^{e}	1.60^{c}

[a]Values followed by the same letter in the same column are not significantly different ($P < 0.05$).

Table 2. Power law parameters for cooking water at different solid concentration/batch number and temperatures of 25 and 80 °C

Temperature (°C)	Batch number	Solid concentration (%)	n (−)	K ($mPa \cdot s^n$)	R^2
25	1	0.53	0.986 ± 0.016	1.4 ± 0.4	0.997
	2	0.77	0.914 ± 0.012	$2.8 \pm 0.3 \cdot 10^{-2}$	0.998
	3	1.37	0.899 ± 0.008	$4.0 \pm 0.3 \cdot 10^{-2}$	0.999
	4	1.62	0.896 ± 0.002	$5.3 \pm 0.3 \cdot 10^{-2}$	0.999
	5	2.12	0.885 ± 0.005	$8.3 \pm 0.9 \cdot 10^{-2}$	0.999
	6	2.41	0.888 ± 0.004	$9.6 \pm 3.1 \cdot 10^{-2}$	0.999
	7	2.65	0.894 ± 0.001	$11.9 \pm 0.7 \cdot 10^{-2}$	1.000
	9	3.28	0.864 ± 0.005	18.9 ± 0.2	0.999
	12	3.66	0.834 ± 0.005	30.7 ± 2.2	1.000
80	1	0.53	0.969 ± 0.039	0.5 ± 0.1	0.982
	2	0.77	1.021 ± 0.037	0.8 ± 0.1	0.994
	3	1.37	1.004 ± 0.043	1.2 ± 0.2	0.998
	4	1.62	0.944 ± 0.026	2.0 ± 0.2	0.999
	5	2.12	0.920 ± 0.059	3.2 ± 1.0	1.000
	6	2.41	0.924 ± 0.029	3.3 ± 0.4	0.999
	7	2.65	0.917 ± 0.038	4.4 ± 0.9	1.000
	9	3.28	0.811 ± 0.133	12.5 ± 1.0	1.000
	12	3.66	0.777 ± 0.133	21.9 ± 2.4	1.000

Power law parameters: K, consistency coefficient; n, flow behaviour index; means ± standard deviation

Table 3. Concentration dependence coefficients (± standard errors) for consistency coefficient of cooking water (Eq. 3)

Temperature (°C)	*a*	*b*	R^2
25	$1.21\cdot10^{-3} \pm 0.09$	0.87 ± 0.04	0.98
80	$0.27\cdot10^{-3} \pm 0.15$	1.14 ± 0.06	0.98

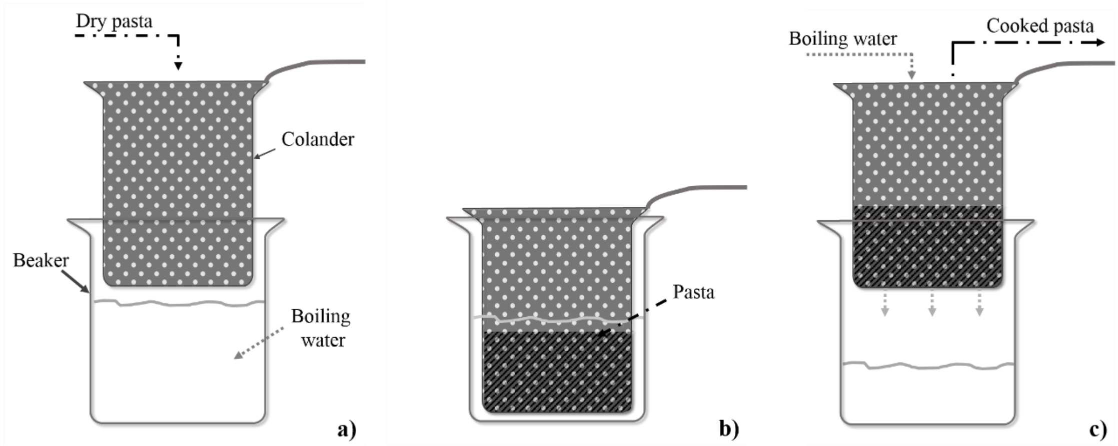
Dry pasta
Colander
Beaker
Boiling water
a)
Pasta
b)
Boiling water
Cooked pasta
c)

Figure 1.

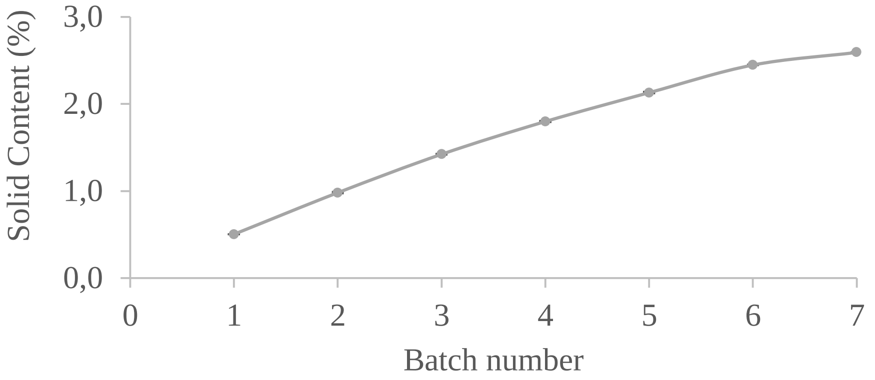

Figure 2.

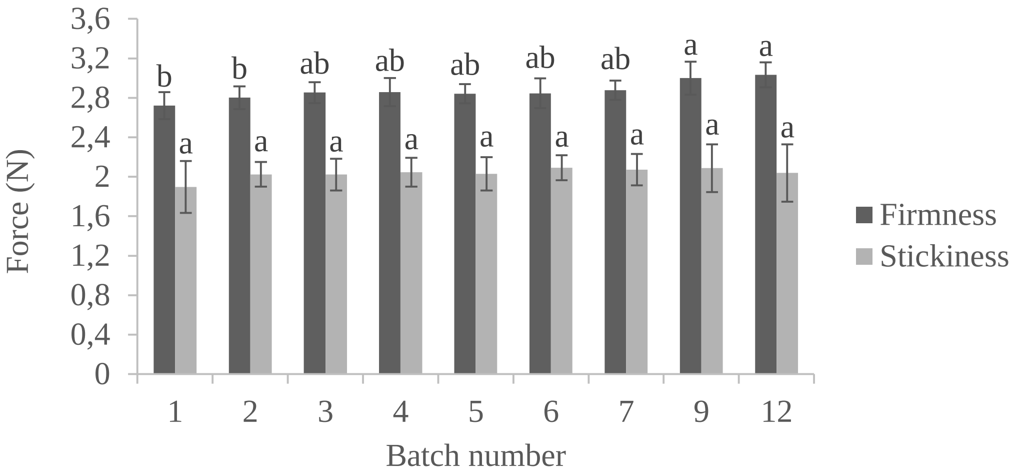
3,6
3,2
2,8
2,4
2
1,6
1,2
0,8
0,4
0
Force (N)
b
b
ab
ab
ab
ab
ab
a
a
a
a
a
a
a
a
a
a
a
1
2
3
4
5
6
7
9
12
Batch number
Firmness
Stickiness

Figure 3.

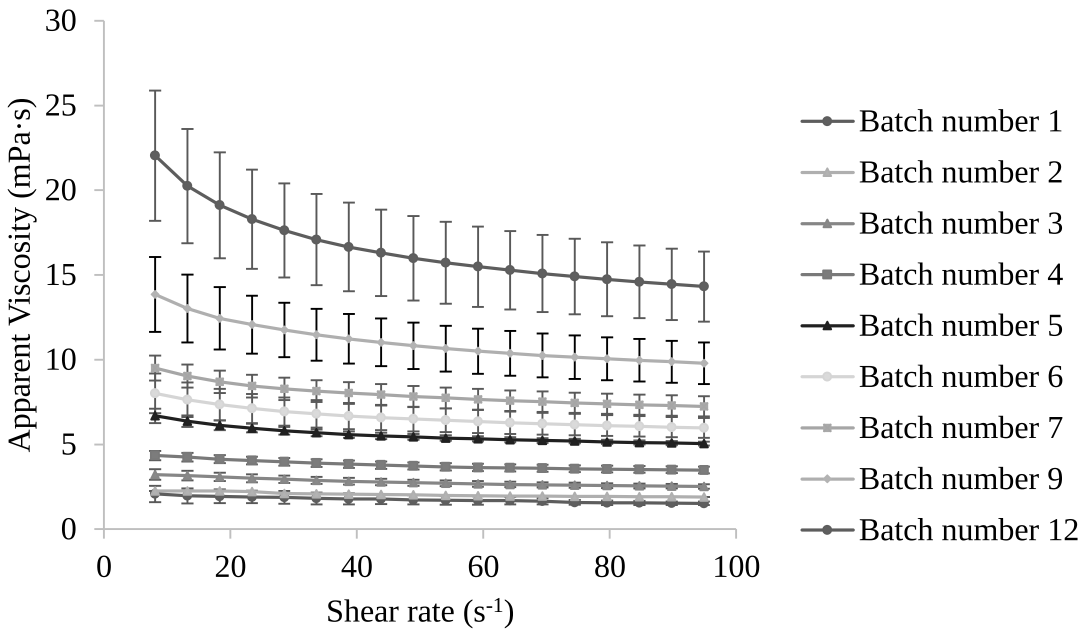
30
25
20
15
10
5
0
Apparent Viscosity (mPa·s)
0
20
40
60
80
100
Shear rate (s-1)
Batch number 1
Batch number 2
Batch number 3
Batch number 4
Batch number 5
Batch number 6
Batch number 7
Batch number 9
Batch number 12

Figure 4.